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(54) **PHASE GRADIENT NANOCOMPOSITE WINDOW FABRICATION AND METHOD OF FABRICATING DURABLE OPTICAL WINDOWS**

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(Continued)

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B29C 41/04 (2006.01)
G02B 1/11 (2015.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G02B 1/11*** (2013.01); ***B29C 41/04*** (2013.01); ***B32B 1/00*** (2013.01); ***B32B 5/16*** (2013.01); ***B32B 7/022*** (2019.01); ***B82Y 30/00*** (2013.01); ***C04B 35/01*** (2013.01); ***C04B 35/053*** (2013.01); ***C04B 35/505*** (2013.01); ***C04B 35/645*** (2013.01); ***C04B 35/6455*** (2013.01); ***C04B 40/0021*** (2013.01); ***F42B 10/46*** (2013.01); ***G02B 1/10*** (2013.01); ***G02B 1/16*** (2015.01); ***G02B 5/0221*** (2013.01); ***G02B 5/0294*** (2013.01); ***H01Q 1/42*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC B29C 41/04; B29K 2995/0011; B29K 2995/0026; C04B 40/0021
See application file for complete search history.

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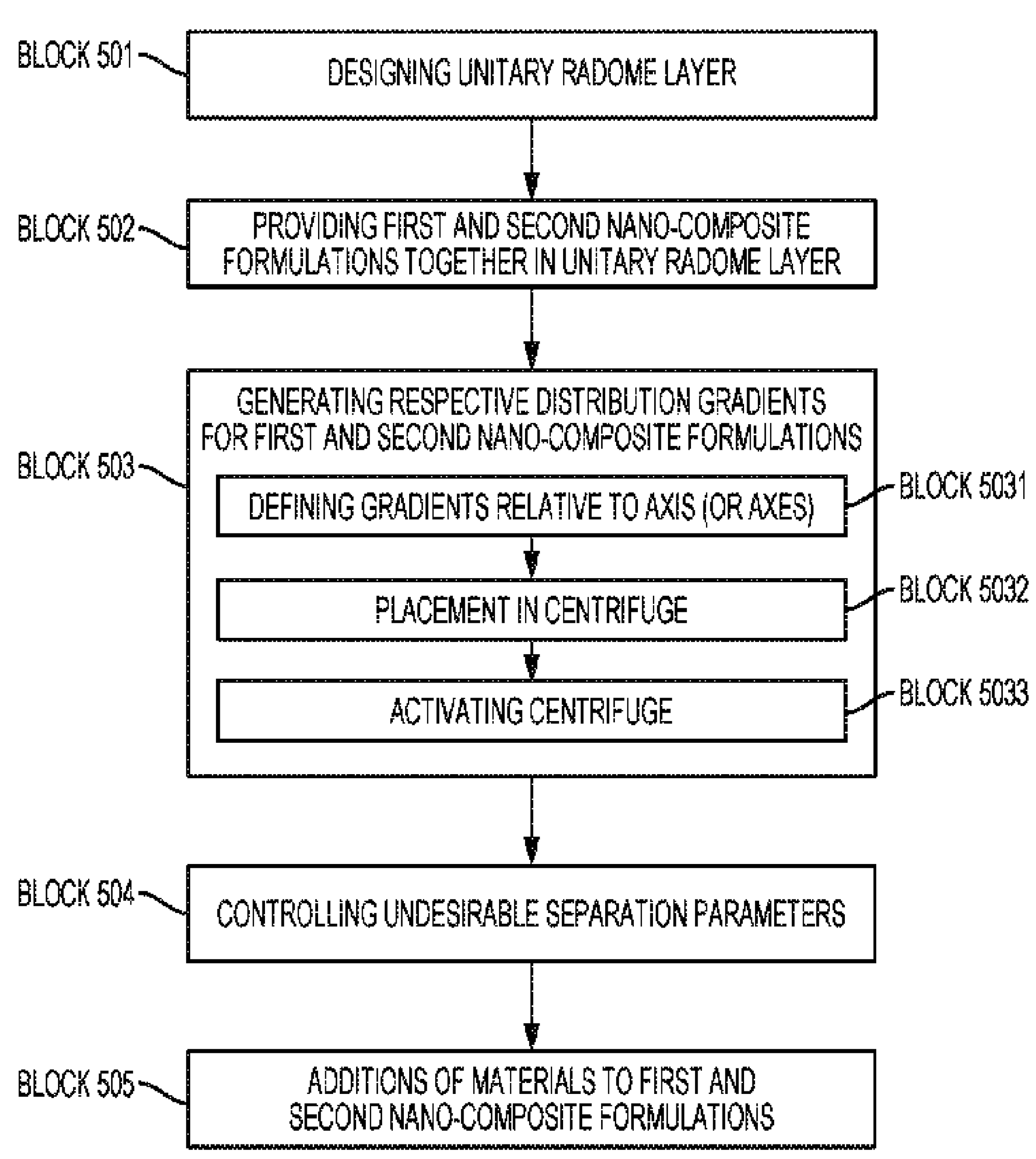
(57) **ABSTRACT**

A unitary radome layer assembly is provided and includes a first nanocomposite formulation and a second nanocomposite formulation. The first and second nanocomposite formulations are provided together in a unitary radome layer with respective distribution gradients.

12 Claims, 7 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 62/404,526, filed on Oct. 5, 2016.

(51) **Int. Cl.**

H01Q 1/42	(2006.01)
F42B 10/46	(2006.01)
H01Q 15/00	(2006.01)
B82Y 30/00	(2011.01)
G02B 1/10	(2015.01)
C04B 35/053	(2006.01)
C04B 35/505	(2006.01)
G02B 5/02	(2006.01)
C04B 35/645	(2006.01)
C04B 35/01	(2006.01)
C04B 40/00	(2006.01)
B32B 7/022	(2019.01)
G02B 1/16	(2015.01)
H05K 9/00	(2006.01)
B32B 1/00	(2006.01)
B32B 5/16	(2006.01)
B29L 11/00	(2006.01)
B29L 31/00	(2006.01)

(52) **U.S. Cl.**

CPC ***H01Q 15/0013*** (2013.01); ***H05K 9/009*** (2013.01); *B29K 2995/0011* (2013.01); *B29K 2995/0026* (2013.01); *B29L 2011/00* (2013.01); *B29L 2031/778* (2013.01); *B32B 2307/212* (2013.01); *B32B 2307/412* (2013.01); *B32B 2551/00* (2013.01); *C04B 2235/3206* (2013.01); *C04B 2235/3225* (2013.01); *C04B 2235/60* (2013.01); *C04B 2235/75* (2013.01); *C04B 2235/9653* (2013.01)

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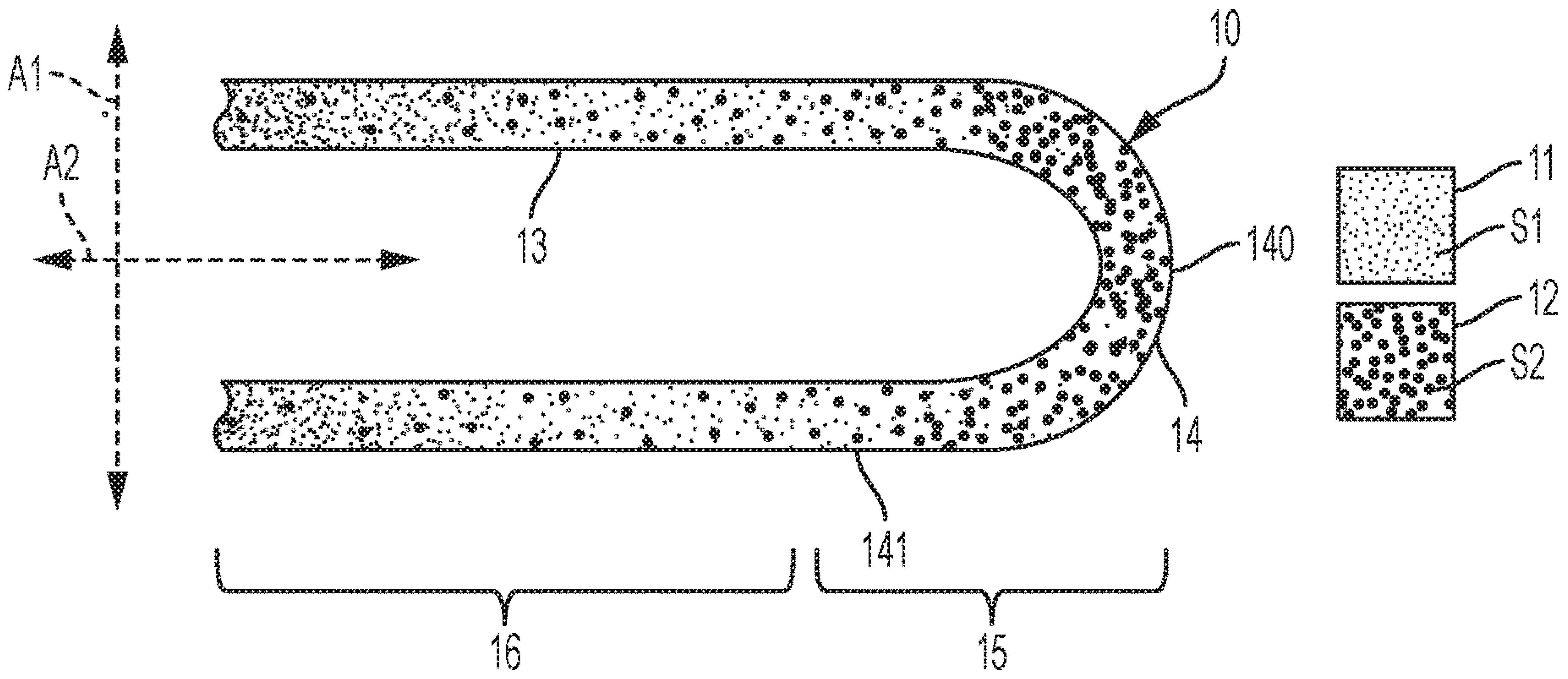

FIG. 1

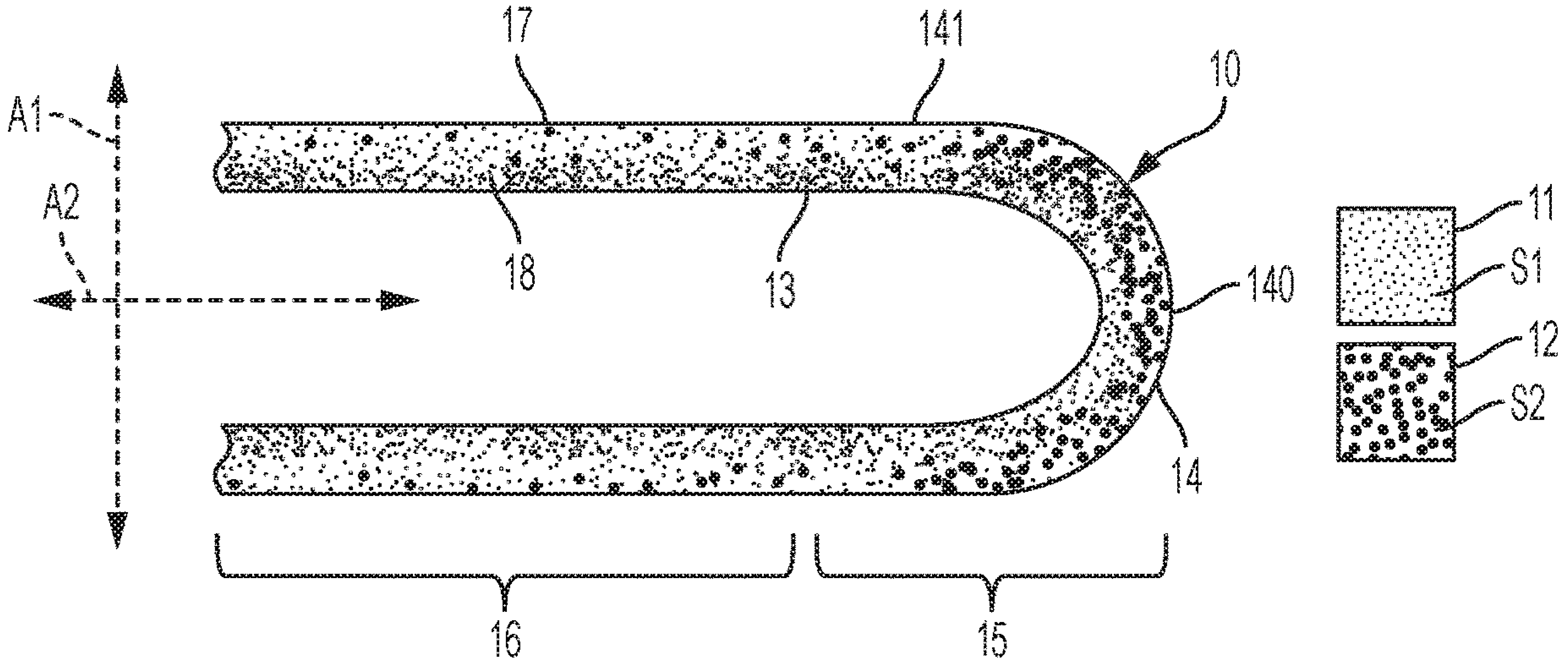

FIG. 2

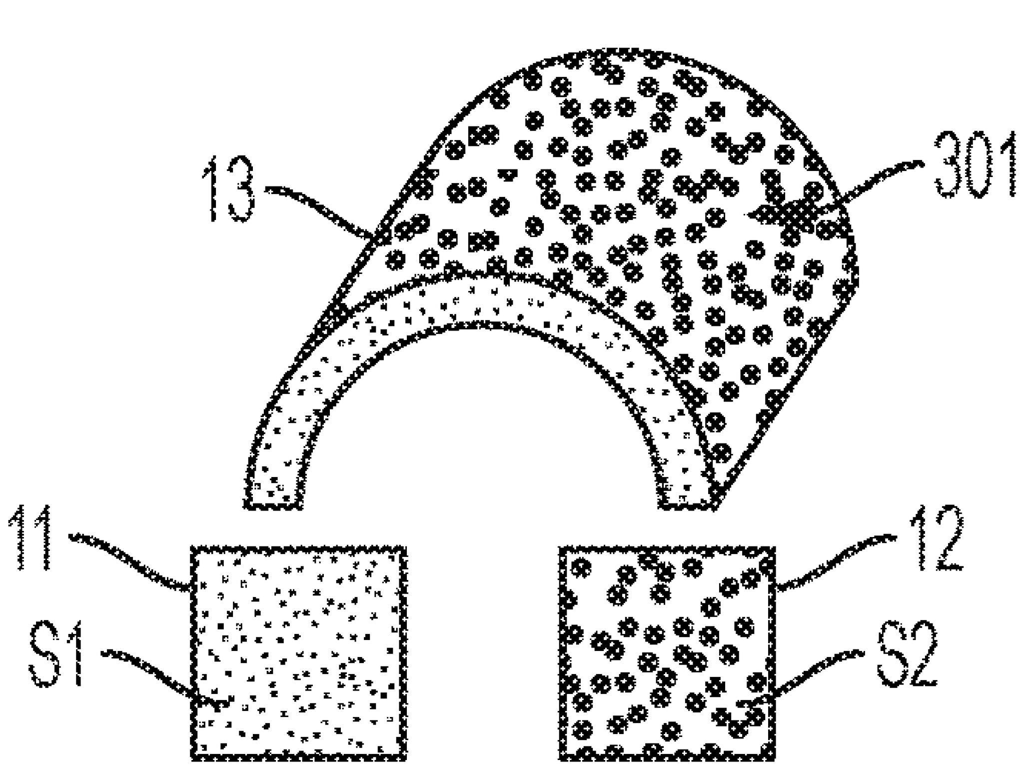

FIG. 3

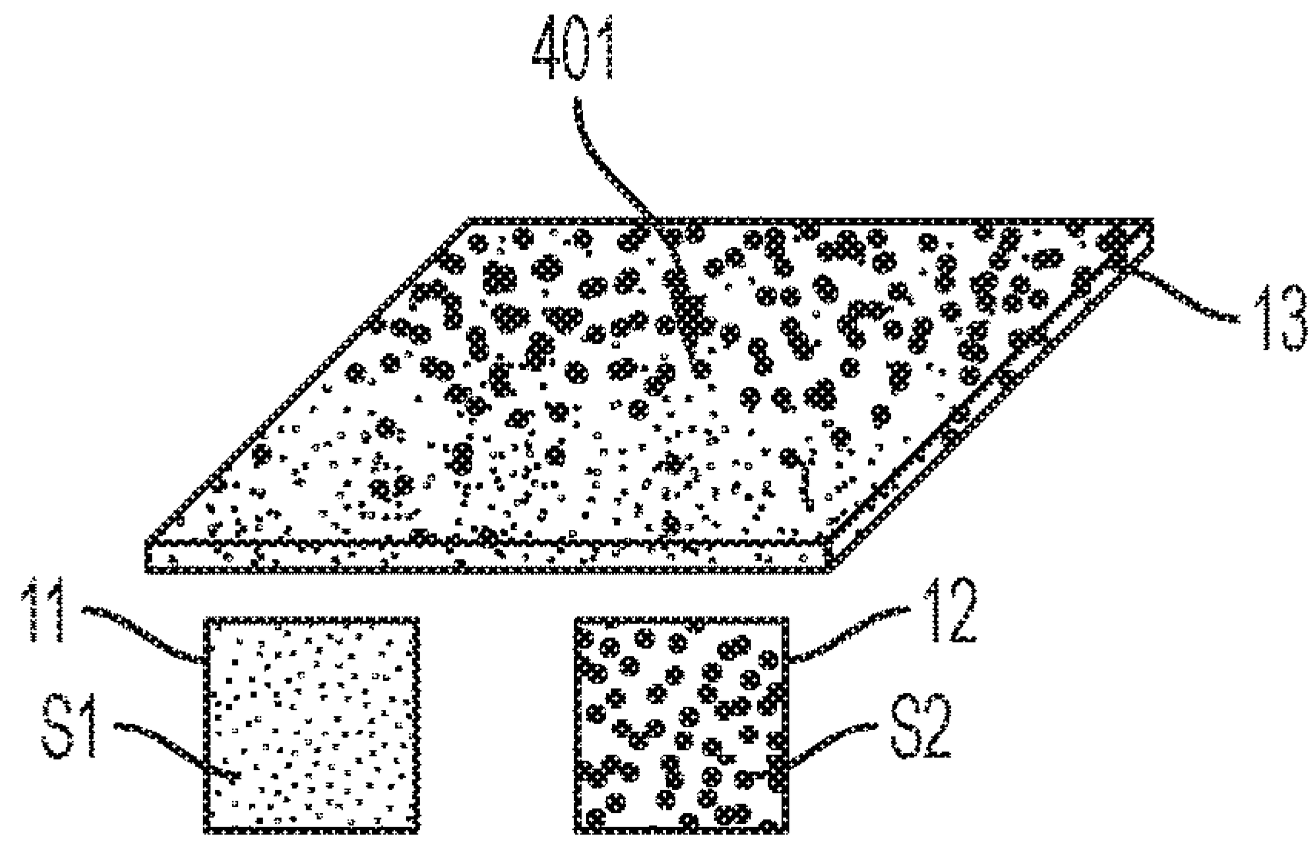

FIG. 4

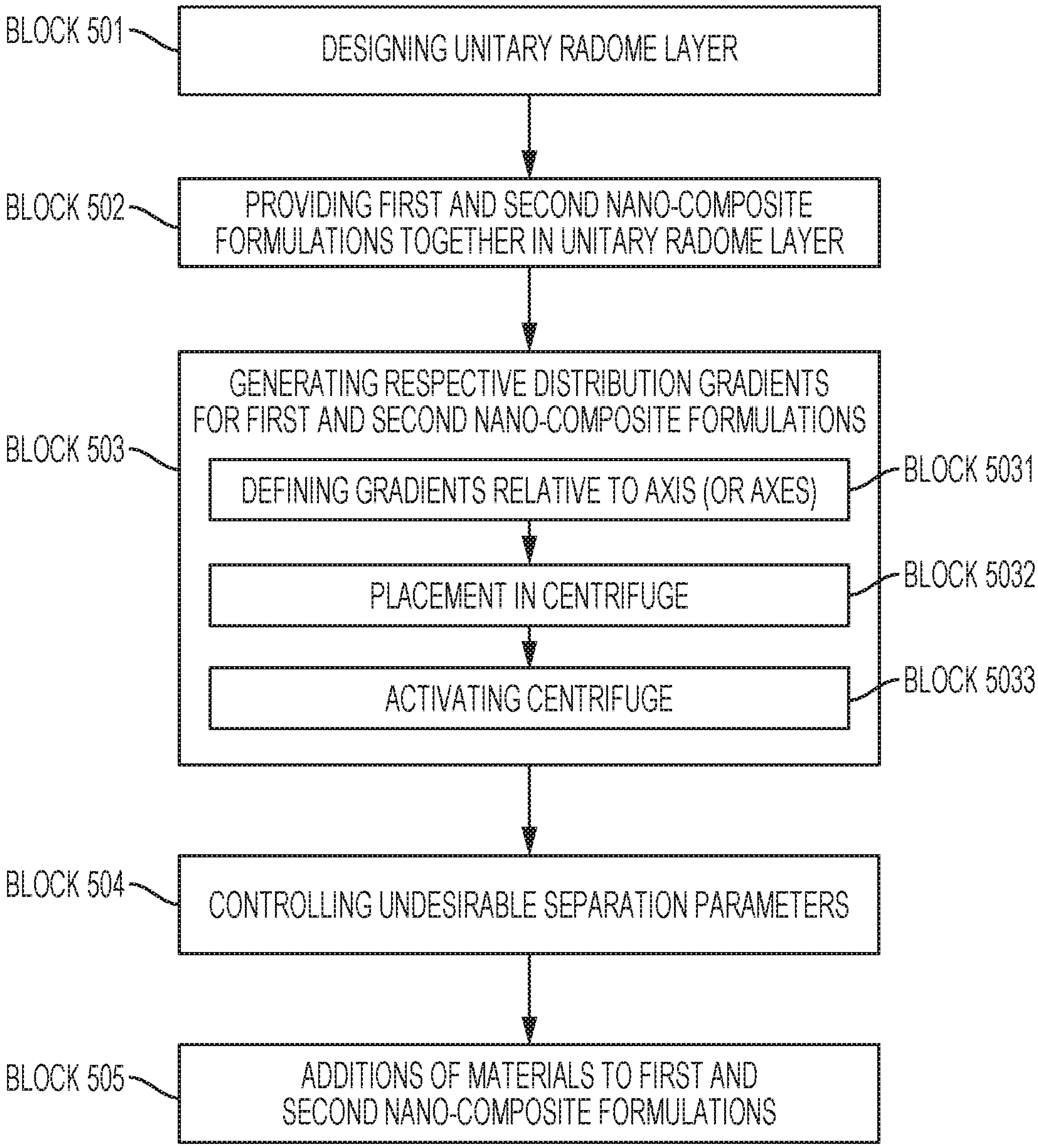
BLOCK 501
DESIGNING UNITARY RADOME LAYER
BLOCK 502
PROVIDING FIRST AND SECOND NANO-COMPOSITE FORMULATIONS TOGETHER IN UNITARY RADOME LAYER
BLOCK 503
GENERATING RESPECTIVE DISTRIBUTION GRADIENTS FOR FIRST AND SECOND NANO-COMPOSITE FORMULATIONS
BLOCK 5031
DEFINING GRADIENTS RELATIVE TO AXIS (OR AXES)
BLOCK 5032
PLACEMENT IN CENTRIFUGE
BLOCK 5033
ACTIVATING CENTRIFUGE
BLOCK 504
CONTROLLING UNDESIRABLE SEPARATION PARAMETERS
BLOCK 505
ADDITIONS OF MATERIALS TO FIRST AND SECOND NANO-COMPOSITE FORMULATIONS

FIG. 5

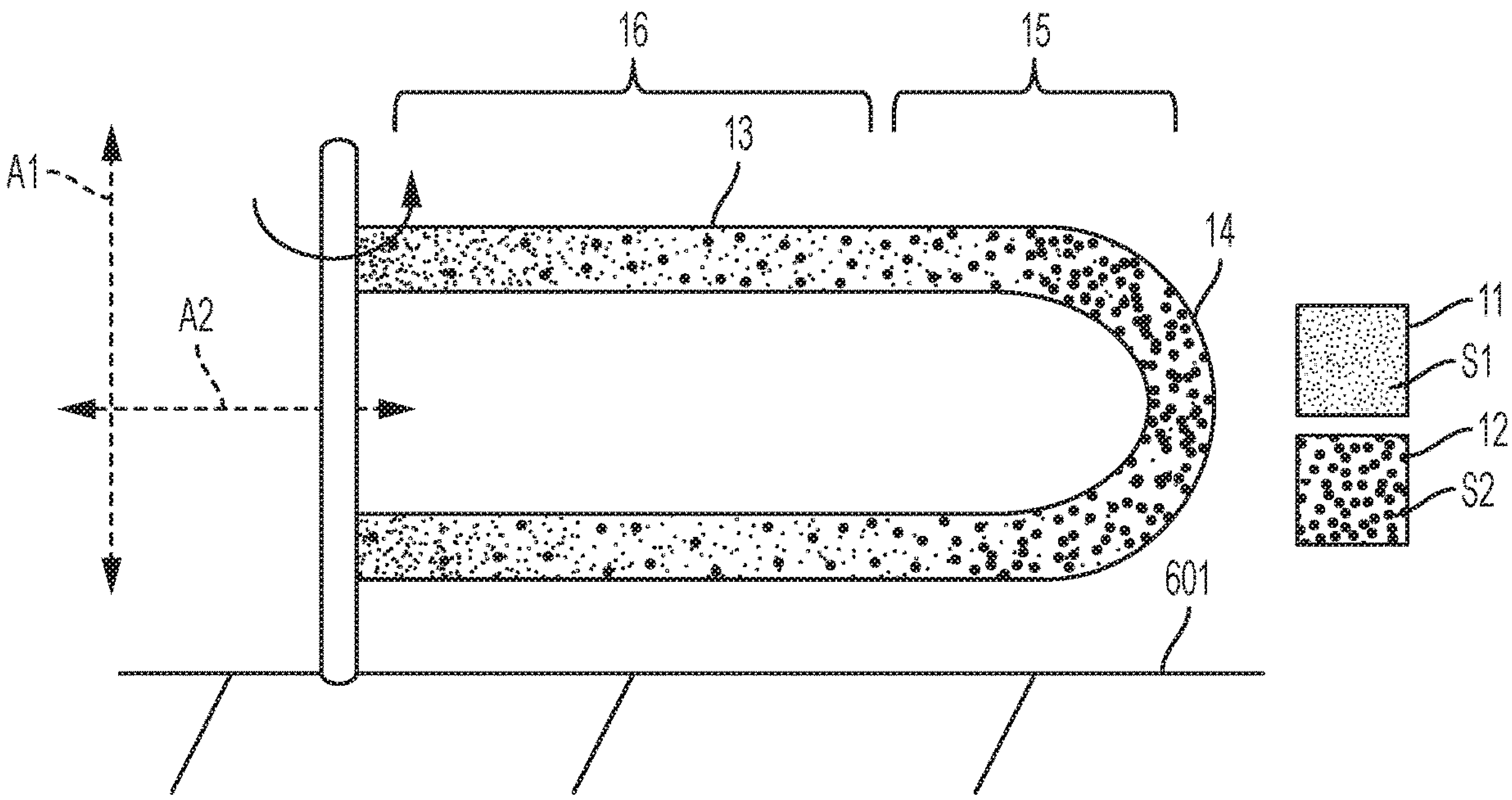

FIG. 6

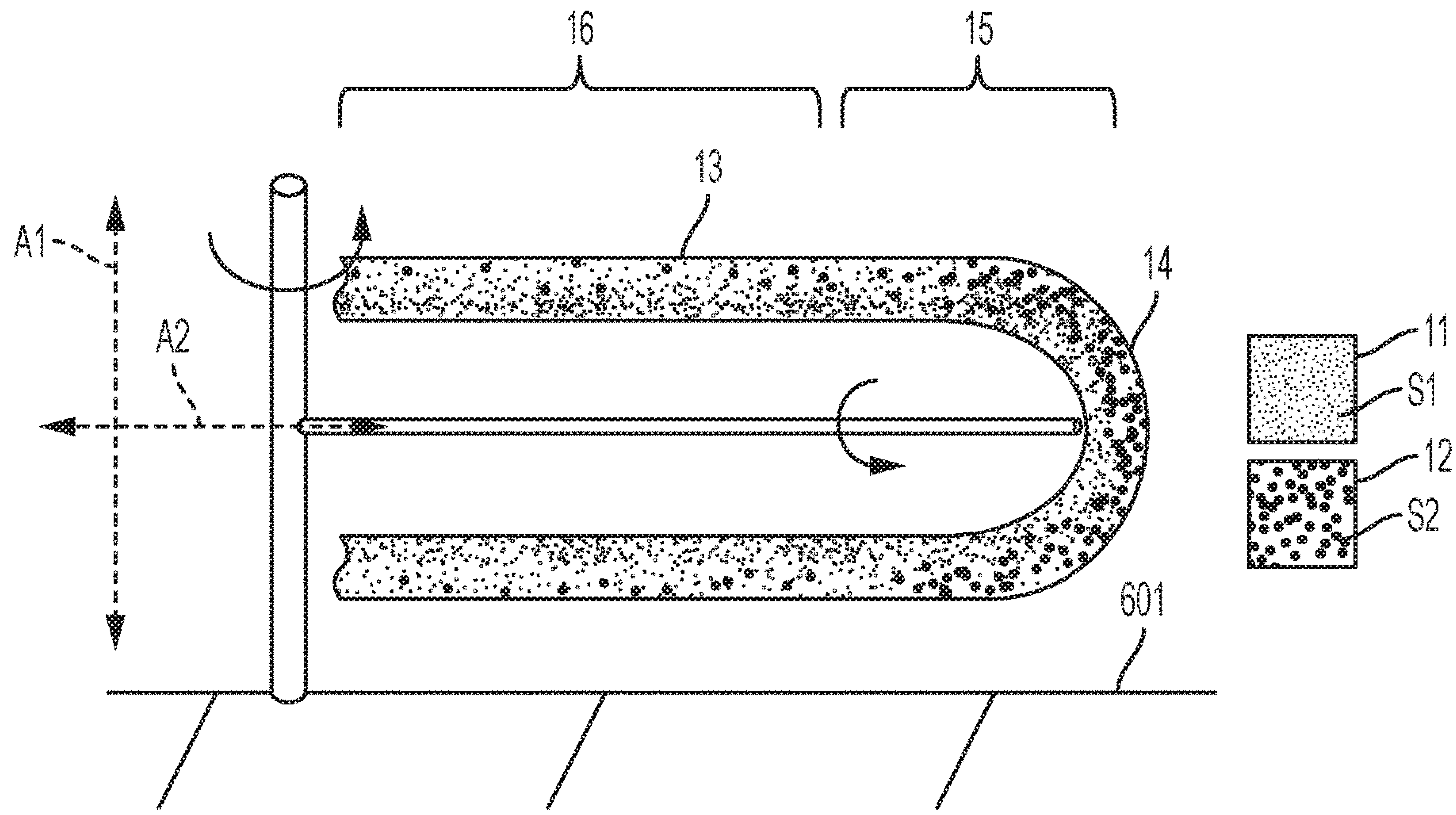

FIG. 7

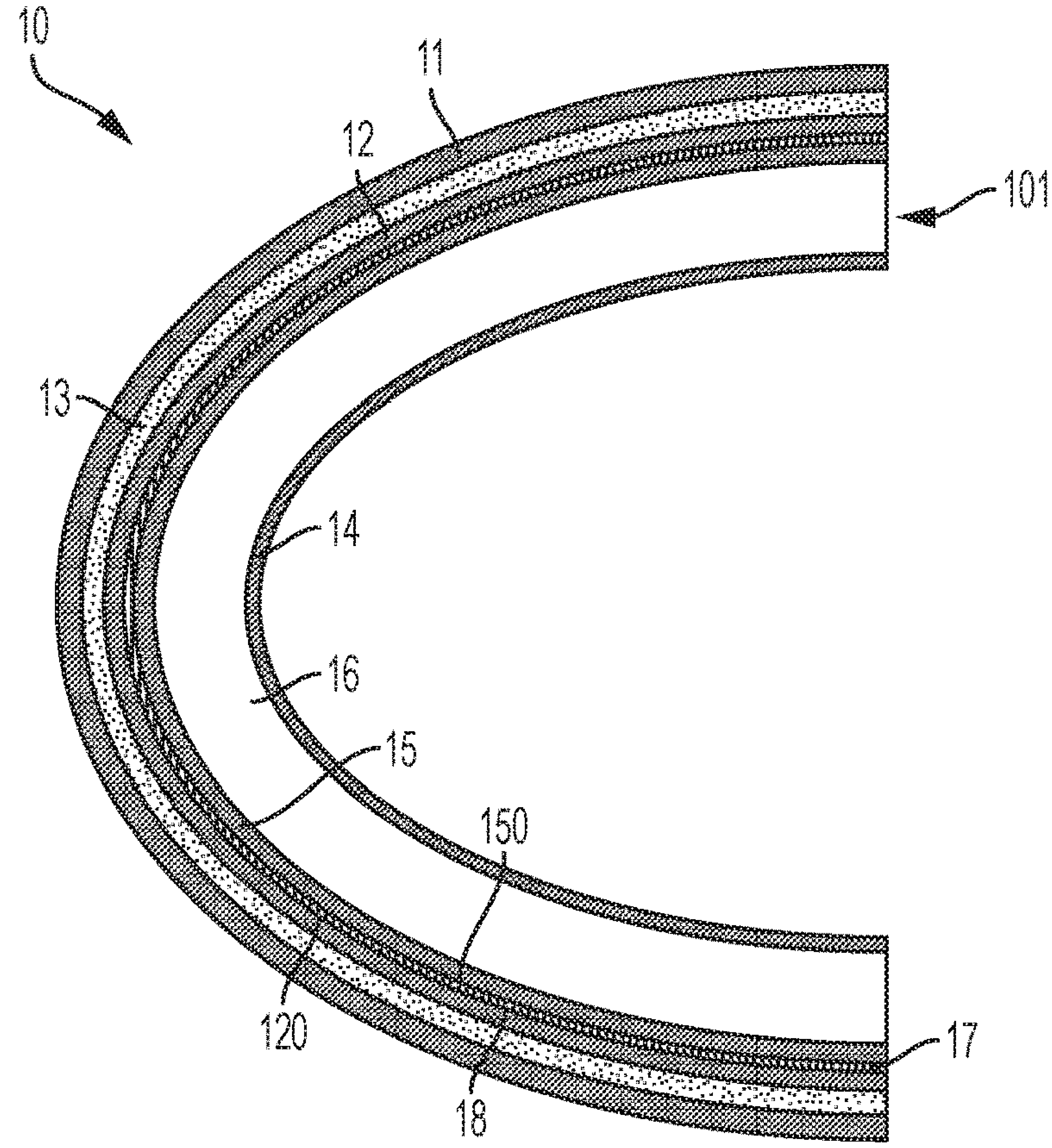

FIG. 8

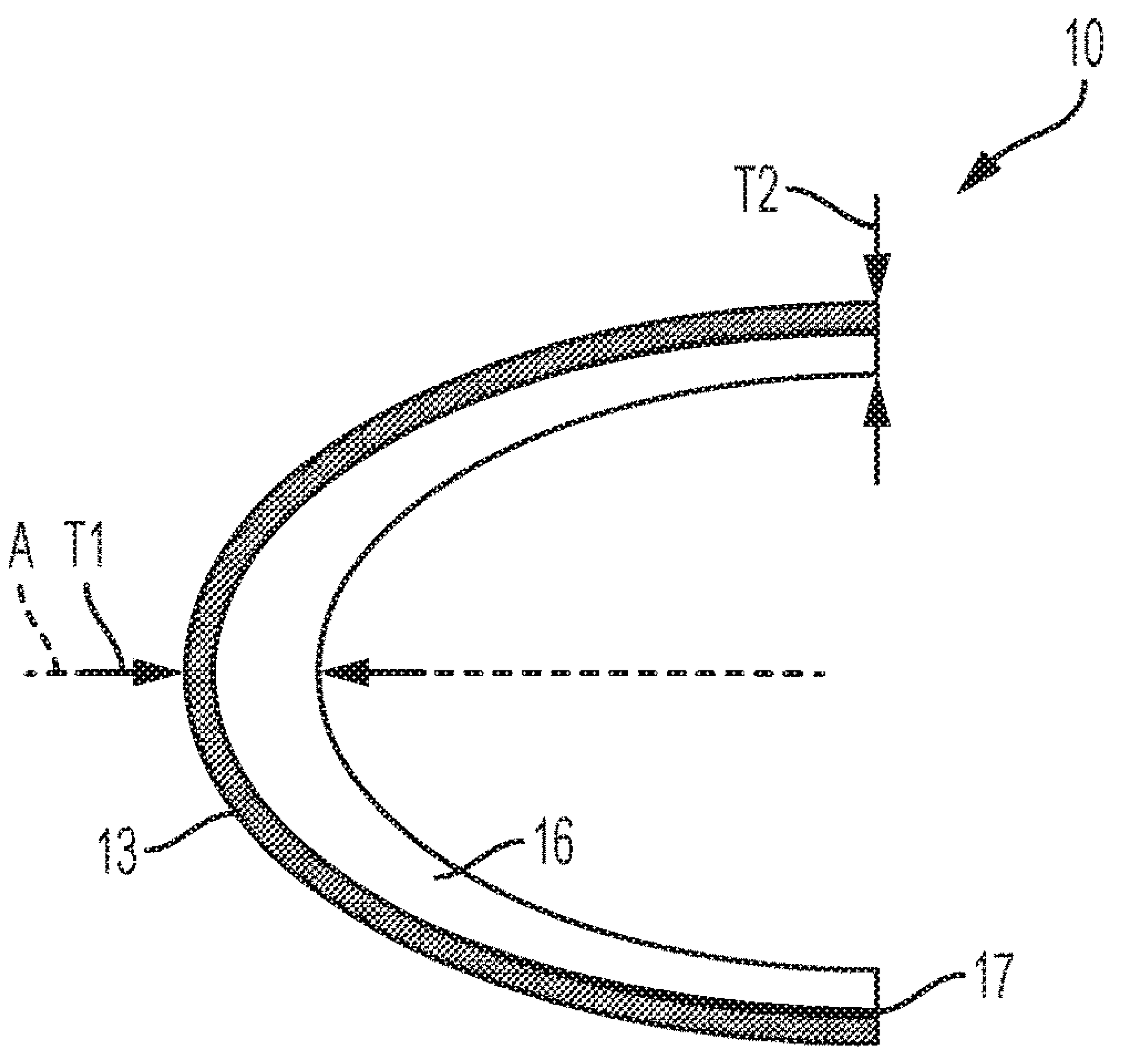

FIG. 9

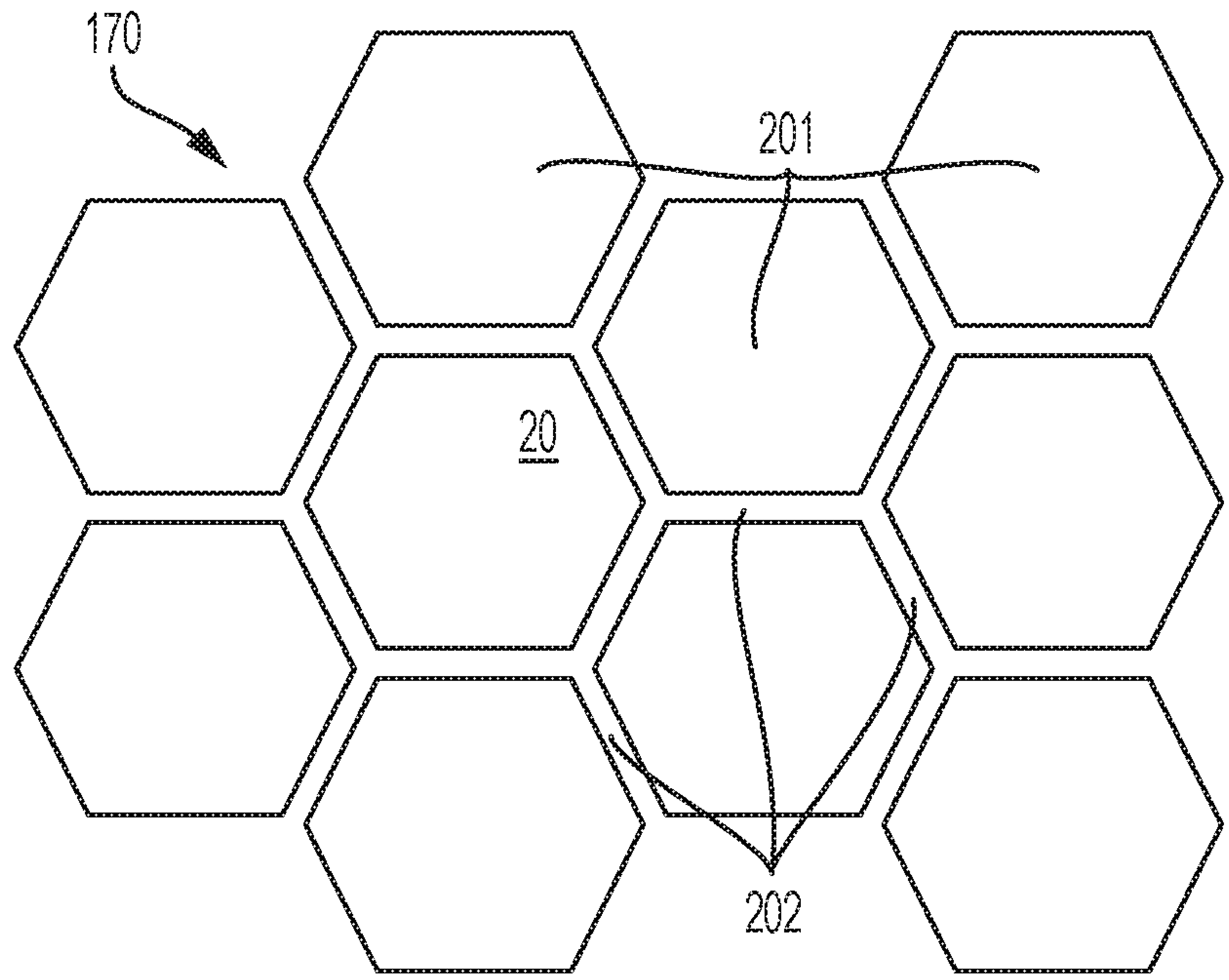

FIG. 10

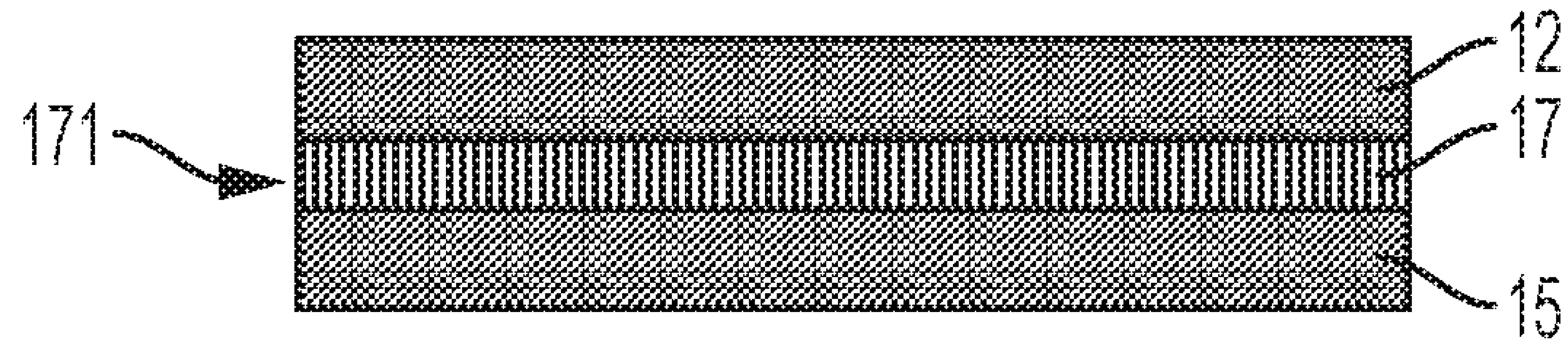

FIG. 11

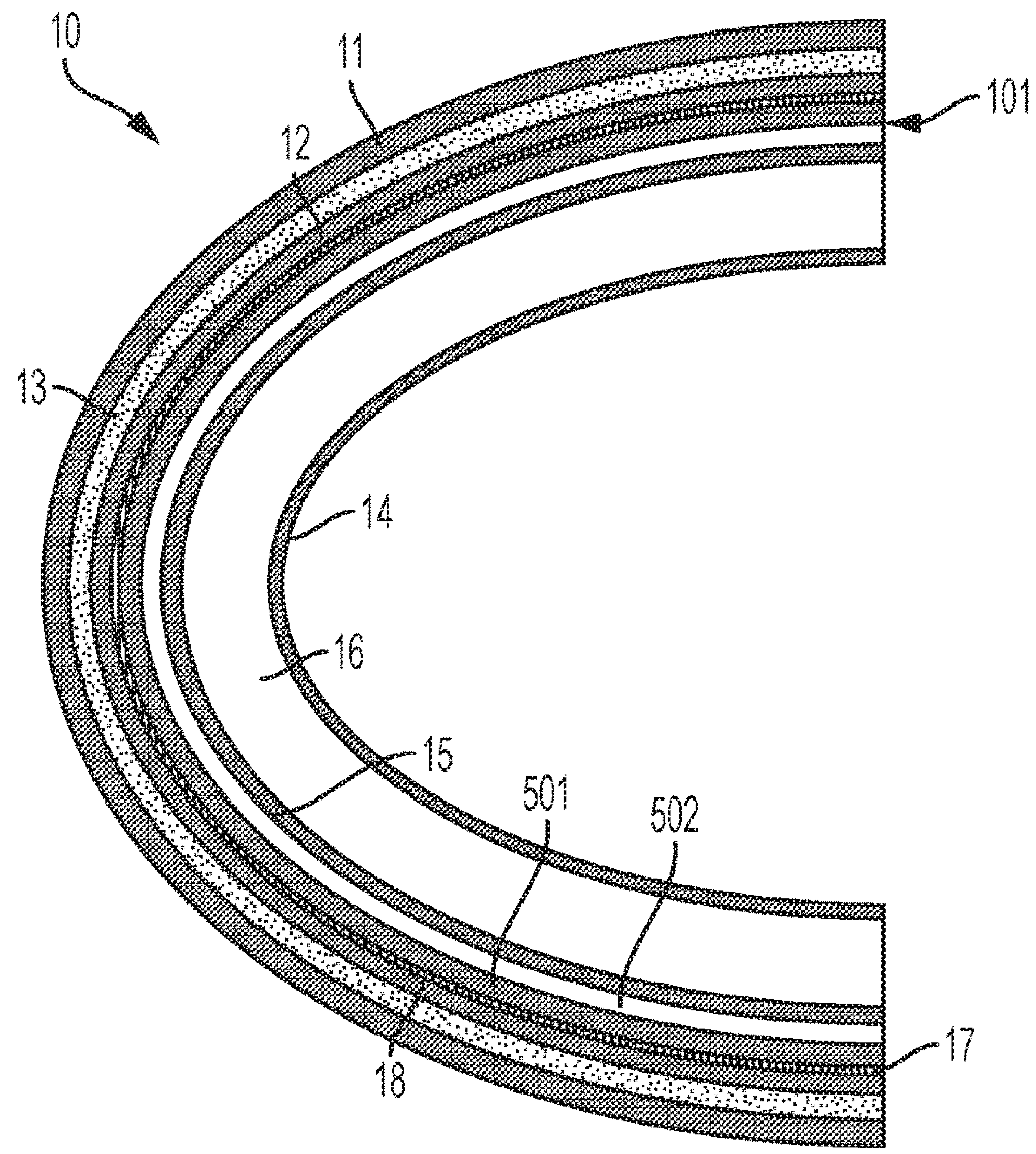
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FIG. 12

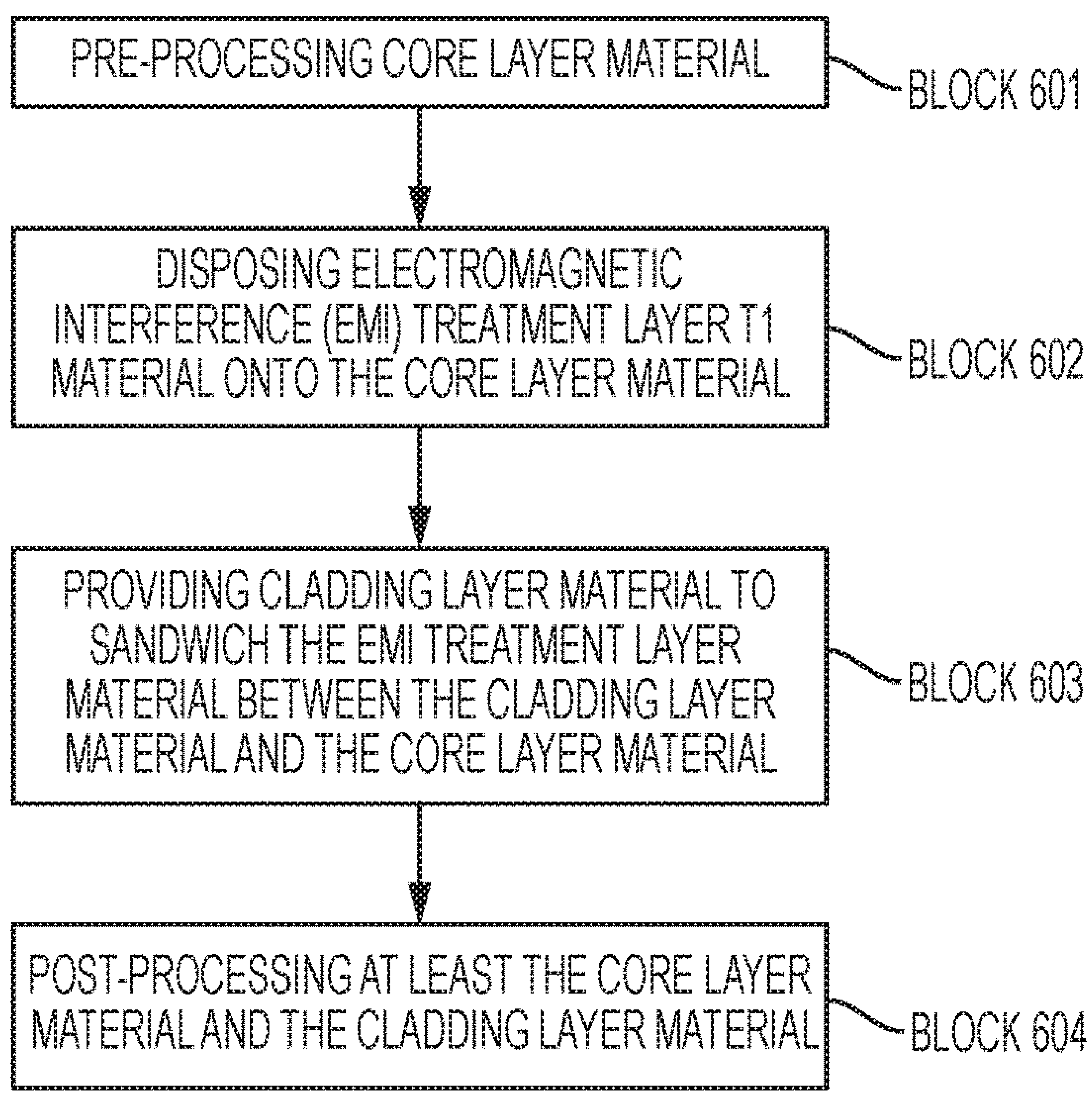
PRE-PROCESSING CORE LAYER MATERIAL
BLOCK 601
DISPOSING ELECTROMAGNETIC INTERFERENCE (EMI) TREATMENT LAYER T1 MATERIAL ONTO THE CORE LAYER MATERIAL
BLOCK 602
PROVIDING CLADDING LAYER MATERIAL TO SANDWICH THE EMI TREATMENT LAYER MATERIAL BETWEEN THE CLADDING LAYER MATERIAL AND THE CORE LAYER MATERIAL
BLOCK 603
POST-PROCESSING AT LEAST THE CORE LAYER MATERIAL AND THE CLADDING LAYER MATERIAL
BLOCK 604

FIG. 13

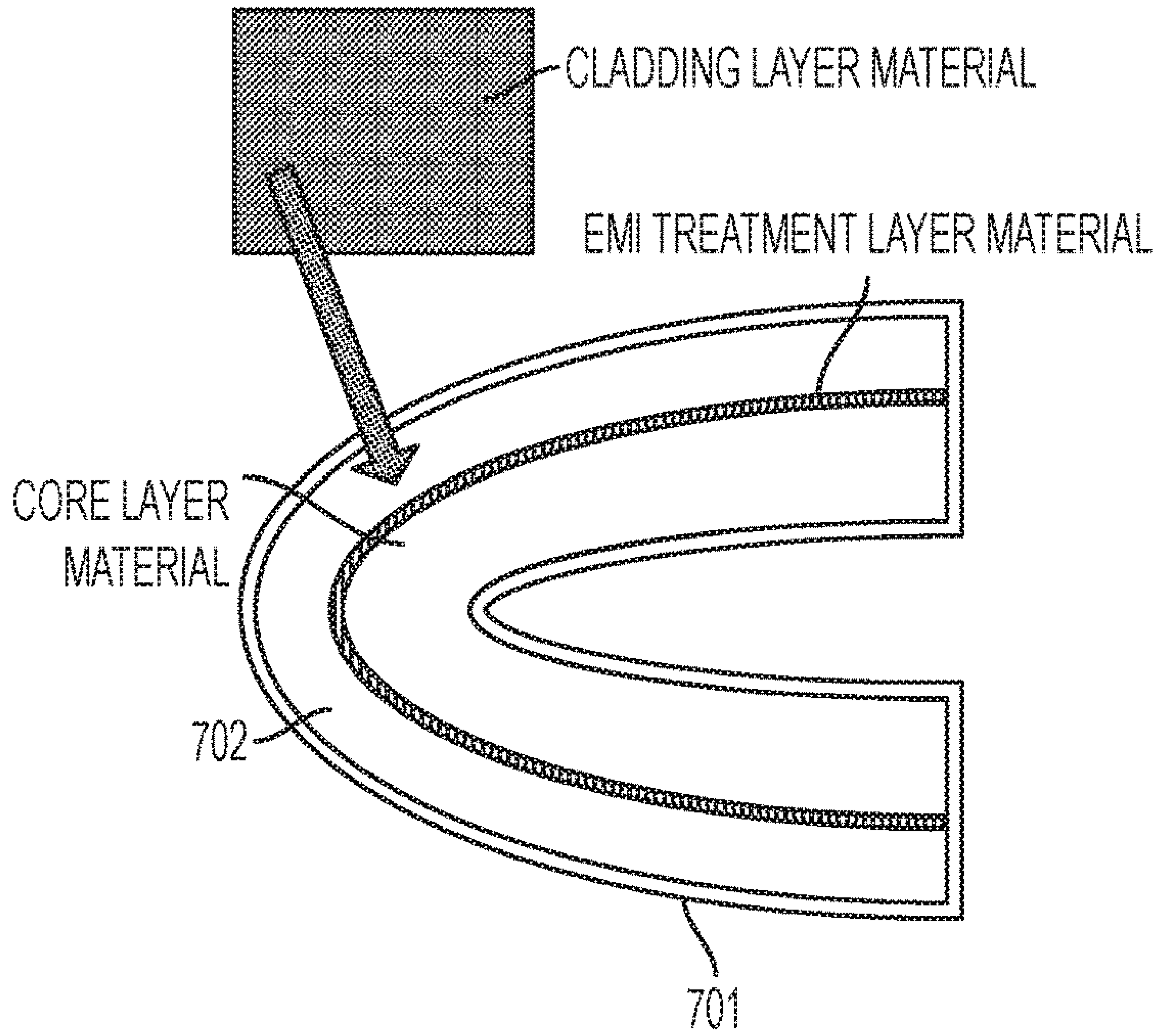
CLADDING LAYER MATERIAL
EMI TREATMENT LAYER MATERIAL
CORE LAYER MATERIAL
702
701

FIG. 14

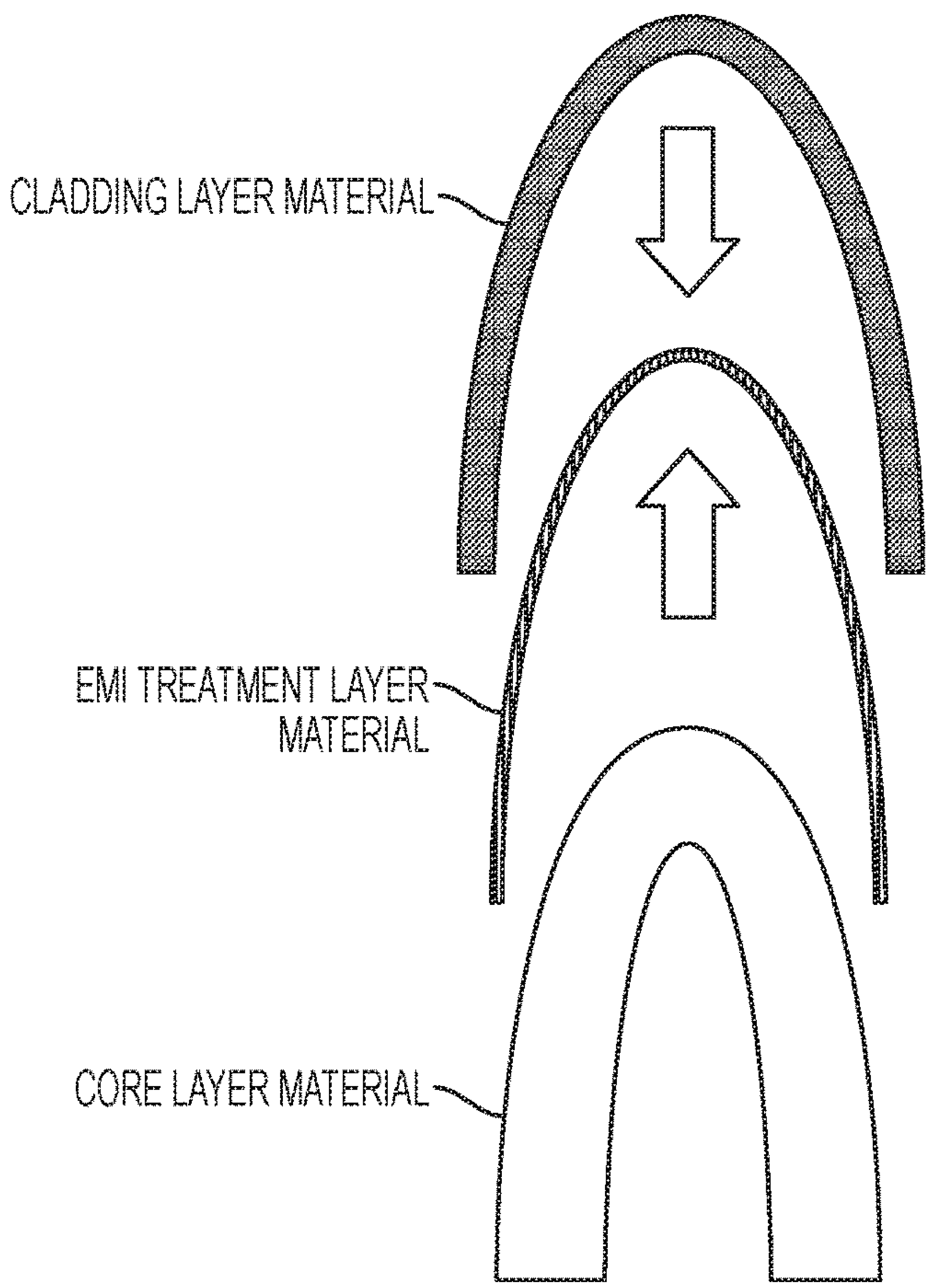
CLADDING LAYER MATERIAL
EMI TREATMENT LAYER MATERIAL
CORE LAYER MATERIAL

FIG. 15

PHASE GRADIENT NANOCOMPOSITE WINDOW FABRICATION AND METHOD OF FABRICATING DURABLE OPTICAL WINDOWS

DOMESTIC BENEFIT/NATIONAL STAGE INFORMATION

The present application is a divisional application that claims the benefit of priority of U.S. non-provisional patent application Ser. No. 15/724,695, which was entitled "PHASE GRADIENT NANOCOMPOSITE WINDOW FABRICATION AND METHOD OF FABRICATING DURABLE OPTICAL WINDOWS", filed on Oct. 4, 2017, that claims the benefit of priority to U.S. provisional patent application Ser. No. 62/404,526, which was entitled "PHASE GRADIENT NANOCOMPOSITE WINDOW FABRICATION AND METHOD OF FABRICATING DURABLE OPTICAL WINDOWS", filed on Oct. 5, 2016. The entire contents of U.S. non-provisional patent application Ser. No. 15/724,695 and U.S. provisional patent application Ser. No. 62/404,526 are incorporated herein by reference.

BACKGROUND

The present disclosure relates to a phase gradient nanocomposite window fabrication method and a method of fabricating durable optical windows.

Optical windows used in aircraft and high-speed missiles must meet very aggressive requirements on flexure strength, impact durability and optical transparency. Often these constraints are in conflict such that environmentally rugged windows lack sufficient transparency or spectral bandwidth for future generation optical search and track applications.

Optical windows can be produced by various processes that include, but are not limited to single crystal growth, chemical vapor deposition (CVD) and nanocomposite sintering. Nanocomposites, in particular, are very attractive materials for use in windows because they can combine multiple materials (or phases) to produce a window that is stronger than the windows produced from either phase alone. Nanocomposite-based windows are generally formed using a powder process which allows very large and curved window shapes to be produced in nearly finished shape. This is called near net shaping and in theory could be used to form windows of any desired shape with minimal waste of materials. Other window materials that employ single crystal growth or CVD require that window fabrication start from a large block of material that is sculpted to produce the desired window topology. This is extremely expensive and time consuming as well as being wasteful in terms of material usage.

When compared to the single phase (e.g., CVD) materials, the nanocomposites have certain disadvantages that weigh against their use despite the benefits of near net shaping. For example, optical transparency of nanocomposite windows may suffer from increased optical absorption and scattering that is introduced by the added material or phase. That is, near net shape sintering of zinc sulfide (ZnS), for example, produces a window that is mechanically weak and not normally usable in airborne applications but, while the second phase of material that is added prevents large grain growth during sintering (a key to maintaining hardness), the added hardening agent introduces scattering and absorption effects. This occurs, in particular, in windows formed of zinc sulfide and in windows including an additional second

sulfide phase. Here, while mechanical strength of the window may be dramatically enhanced relative to pure sintered ZnS, the presence of the second sulfide phase can cause strong optical absorption of radiation in a long wave infrared (LWIR) spectral band.

In addition, while certain coatings and electromechanical interference (EMI) treatment layers can be applied to certain windows, such coatings tend to be insufficiently durable. Meanwhile, although mechanical shutters can be used to protect windows in some cases, shutters are not feasible in all cases.

SUMMARY

According to an aspect of the invention, a unitary radome layer assembly is provided and includes a first nanocomposite formulation and a second nanocomposite formulation. The first and second nanocomposite formulations are provided together in a unitary radome layer with respective distribution gradients.

In accordance with additional or alternative embodiments, the respective distribution gradients are defined relative to an axis of the unitary radome layer.

In accordance with additional or alternative embodiments, the respective distribution gradients are defined relative to multiple axes of the unitary radome layer.

In accordance with additional or alternative embodiments, the unitary radome layer has an ogive shape.

In accordance with additional or alternative embodiments, the respective distribution gradients are characterized with an increased distribution of the first nanocomposite formulation remote from a tip of the unitary radome layer with the ogive shape and an increased distribution of the second nanocomposite formulation proximate to the tip of the unitary radome layer with the ogive shape.

In accordance with additional or alternative embodiments, the first nanocomposite formulation includes particles of first sizes, the second nanocomposite formulation includes particles of second sizes, the second sizes being generally larger than the first sizes and the respective distribution gradients are characterized with an increased distribution of the particles of the first sizes remote from a tip of the unitary radome layer with the ogive shape and an increased distribution of the particles of the second sizes proximate to the tip of the unitary radome layer with the ogive shape.

In accordance with additional or alternative embodiments, the unitary radome layer has at least one of an ogive shape, a rounded shape and a flattened shape.

According to another aspect of the invention, a unitary radome layer assembly method is provided and includes designing a unitary radome layer with first and second portions, the first portions being more durable than the second portions and the second portions being more optically transparent than the first portions, providing first and second nanocomposite formulations together in a unitary radome layer mold, the second nanocomposite formulation having a hardener and a higher effective density than the first nanocomposite formulation and generating respective distribution gradients for the first and second nanocomposite formulations prior to curing.

In accordance with additional or alternative embodiments, the generating of the respective distribution gradients includes defining the respective distribution gradients relative to a unitary radome layer axis, placing the unitary radome layer mold with the first and second nanocomposite formulations in a centrifuge and activating the centrifuge to

rotate the unitary radome layer mold with the first and second nanocomposite formulations about the unitary radome layer axis.

In accordance with additional or alternative embodiments, the generating of the respective distribution gradients includes defining the respective distribution gradients relative to multiple unitary radome layer axes, placing the unitary radome layer mold with the first and second nanocomposite formulations in a centrifuge and activating the centrifuge to rotate the unitary radome layer mold with the first and second nanocomposite formulations about the multiple unitary radome layer axes.

In accordance with additional or alternative embodiments, the designing includes designing the unitary radome layer to have at least one of an ogive shape, a rounded shape and a flattened shape.

In accordance with additional or alternative embodiments, the method further includes controlling undesirable separation parameters of the first and second nanocomposite formulations.

In accordance with additional or alternative embodiments, the controlling of the undesirable separation parameters includes ultrasonic assist processes.

In accordance with additional or alternative embodiments, the method further includes adding materials to at least one of the first and second nanocomposite formulations to adjust at least one of respective effective densities and respective sedimentation rates thereof.

According to yet another aspect of the invention, a unitary radome layer assembly method is provided and includes designing an ogive shaped unitary radome layer comprising a tip and with first and second portions, the first portions being disposed proximate to the tip and being more durable than the second portions and the second portions being disposed remotely from the tip and being more optically transparent than the first portions, providing first and second nanocomposite formulations together in a unitary radome layer mold having an ogive shape, the second nanocomposite formulation having a hardener and a higher effective density than the first nanocomposite formulation and generating respective distribution gradients for the first and second nanocomposite formulations relative to an axis of the ogive shape prior to curing.

In accordance with additional or alternative embodiments, the generating of the respective distribution gradients includes defining the respective distribution gradients relative to a lateral axis of the unitary radome layer which is transversely oriented relative to a central longitudinal axis thereof, placing the unitary radome layer mold with the first and second nanocomposite formulations in a centrifuge and activating the centrifuge to rotate the unitary radome layer mold with the first and second nanocomposite formulations about the lateral axis.

In accordance with additional or alternative embodiments, the generating of the respective distribution gradients includes defining the respective distribution gradients relative to the lateral axis and an additional axis and activating the centrifuge to rotate the unitary radome layer mold with the first and second nanocomposite formulations about the lateral axis and the additional axis.

In accordance with additional or alternative embodiments, the method further includes controlling undesirable separation parameters of the first and second nanocomposite formulations.

In accordance with additional or alternative embodiments, the controlling of the undesirable separation parameters includes an ultrasonic assist process.

In accordance with additional or alternative embodiments, the method further includes adding materials to at least one of the first and second nanocomposite formulations to adjust at least one of respective effective densities and respective sedimentation rates thereof.

These and other advantages and features will become more apparent from the following description taken in conjunction with the drawings.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

For a more complete understanding of this disclosure, reference is now made to the following brief description, taken in connection with the accompanying drawings and detailed description, wherein like reference numerals represent like parts:

FIG. **1** is a side view of a unitary radome layer in accordance with embodiments;

FIG. **2** is a side view of a unitary radome layer in accordance with further embodiments;

FIG. **3** is a perspective view of a unitary radome layer in accordance with alternative embodiments;

FIG. **4** is a perspective view of a unitary radome layer in accordance with alternative embodiments;

FIG. **5** is a flow diagram illustrating a unitary radome layer assembly method in accordance with embodiments;

FIG. **6** is a schematic illustration of a centrifuge used to generate a distribution gradient in a unitary radome layer prior to curing or sintering in accordance with embodiments;

FIG. **7** is a schematic illustration of a centrifuge used to generate a distribution gradient in a unitary radome layer prior to curing or sintering in accordance with further embodiments;

FIG. **8** shows a side view of an optical window in accordance with embodiments;

FIG. **9** shows a side view of a simplified version of the optical window in accordance with further embodiments;

FIG. **10** shows an EMI treatment layer of the optical windows of FIGS. **8** and **9** in accordance with alternative embodiments;

FIG. **11** shows an EMI treatment layer of the optical windows of FIGS. **8** and **9** in accordance with alternative embodiments;

FIG. **12** shows a side view of an optical window with a thermal management space in accordance with embodiments;

FIG. **13** is a flow diagram illustrating a method of assembling an optical window in accordance with embodiments;

FIG. **14** is a schematic illustration of a fixture for providing an optical window with a cladding layer in accordance with embodiments; and

FIG. **15** is a schematic illustration of a method of sandwiching an EMI treatment layer between core and cladding layers of an optical window in accordance with embodiments.

DETAILED DESCRIPTION

As will be discussed below, potentially quite large and curved optical widows with excellent long-wave and mid-wave broadband transparency and high mechanical durability are provided. The windows are made of very durable nanocomposite materials with high optical transparency and are formed based upon the fact that optical transparency is required of the entire bulk of the window while durability is only required at the surface of the material that is exposed to environmental effects. A centrifuge is used to increase the density of the hardening agent near the outer surface of the windows to increase mechanical strength where it is most needed while reducing or eliminating the hardening agent in other areas of the window bulk. By maintaining less total volume of hardener, the optical transparency of the window as a whole is relatively improved. Meanwhile, by increasing the density of the hardener at the surface of the window, mechanical durability is improved. The resulting optical and mechanical performance of the "phase gradient" nanocomposite window will exceed that of the current technology and even allow new hardening agents to be introduced without strongly or adversely affecting optical transparency. The use of centrifugal force generated by the centrifuge allows less optically absorbing material to be used in the nanocomposite formulation while actually increasing the mechanical strength of the window and its durability against rain, sand and other impacts. Ultrasonic agitation may be added as a method for performing dry powder centrifugal sedimentation.

With reference to FIG. **1**, a unitary radome layer assembly **10** is provided and includes a first nanocomposite formulation **11** and a second nanocomposite formulation **12**. The second nano-composite formulation **12** has a hardener and a higher effective density than the first nanocomposite formulation **11**. The first nano-composite formulation **11** may be but need not be more optically transparent than the second composite nano-formulation **12** due at least in part to the lack of the hardener in the first nano-composite formulation. The first and second nanocomposite formulations **11** and **12** are provided together in a unitary radome layer **13** with each having a respective distribution gradient defined relative to an axis or to multiple axes of the unitary radome layer **13**.

In accordance with embodiments and, as shown in FIG. **1**, the unitary radome layer **13** may be provided with a nose cone or ogive shape **14** that has a pointed nose cone or ogive tip **140** and curved sidewalls **141** extending in the aft direction from the pointed nose cone or ogive tip **140**. In these and other cases, the respective distribution gradients of the first and second nano-composite formulations **11** and **12** are defined relative to a lateral axis **A1** of the unitary radome layer **13** which is oriented transversely or perpendicularly with respect to a central longitudinal axis **A2** of the unitary radome layer **13**. That is, the lateral axis **A1** may effectively define a first, front or forward portion **15** of the unitary radome layer **13** as being any part of the unitary radome layer **13** that is proximate to the nose cone or ogive tip **140** and a second, rear or aft portion **16** of the unitary radome layer **13** as being any part of the unitary radome layer **13** that is remote from the nose cone or ogive tip **140**.

To the extent that the second nanocompo site formulation **12** has the hardener and a higher effective density than the first nano-composite formulation **11**, the unitary radome layer **13** can be formed and cured (e.g., sintered) such that the distribution gradient of the second nano-composite formulation **12** is characterized in that most of the second nano-composite formulation **12** is located in the forward portion **15** and such that the distribution gradient of the first nano-composite formulation **11** is characterized such that most of the first nano-composite formulation **11** is located in the aft portion **16**. These characterizations of the respective gradients have the following results.

With the first and second nano-composite formulations **11** and **12** generally being located in the aft and forward portions **16** and **15**, respectively, homogeneity within the forward and aft portions **15** and **16** is increased and a tendency of the unitary radome layer **13** to scatter or absorb electro-magnetic (EM) radiation is correspondingly reduced as compared to what would otherwise occur if the first and second nano-composite formulations **11** and **12** were distributed evenly throughout the unitary radome layer **13**.

In addition, with the second nano-composite formulation **12** with the hardener being relatively harder than the first nano-composite formulation **11** and being generally or mostly located in the forward portion **15** where the unitary radome layer **13** is most likely to experience impacts with foreign objects and where optical transmission of signals through the unitary radome layer **13** is generally less important, an overall strength and durability of the unitary radome layer **13** is enhanced without sacrificing useful optical transparency. Meanwhile, with the first nano-composite formulation **11** being relatively more optically transparent than the second nano-composite formulation **12** and being generally or mostly located in the aft portion **16** where optical transmission of signals through the unitary radome layer **13** is most important and where impacts are generally less common, an overall optical transparency of the unitary radome layer **13** is enhanced without sacrificing strength or durability.

With reference to FIG. **2** and in accordance with further embodiments, the unitary radome layer **13** may be provided with the nose cone or ogive shape **14** as in FIG. **1** but with the respective distribution gradients of the first and second nano-composite formulations **11** and **12** defined relative to multiple axes of the unitary radome layer **13**. In these or other cases, the multiple axes may include for example the lateral axis **A1** and the central longitudinal axis **A2**. That is, while the lateral axis **A1** may effectively define the forward and aft portions **15** and **16** of the unitary radome layer **13**, the central longitudinal axis **A2** may define outer portions **17** of the unitary radome layer **13** as being those parts of the unitary radome layer **13** that are proximate to outer surfaces of the nose cone or ogive tip **140** and the sidewalls **141** and inner portions **18** of the unitary radome layer **13** as being those parts of the unitary radome layer **13** that are proximate to interior surfaces of the nose cone or ogive tip **140** and the sidewalls **141**.

In the embodiments of FIG. **2**, the unitary radome layer **13** can be formed and cured (e.g., sintered) such that the distribution gradient of the second nano-composite formulation **12** is characterized in that most of the second nano-composite formulation **12** is located along the outer portions **17** in the forward portion **15** and such that the distribution gradient of the first nano-composite formulation **11** is characterized such that most of the first nano-composite formulation **11** is located along the inner portions **18** in the aft portion **16**.

In accordance with still further embodiments, the first nanocomposite formulation **11** may include yttrium oxide (Y_2O_3) particles of relatively small or first sizes (e.g., as measured in terms of mean or average individual particle diameters) S1 and the second nanocomposite formulation **12** may include magnesium oxide (MgO) particles of relatively large or second sizes (e.g., as measured again in terms of mean or average individual particle diameters) S2 where the second sizes S2 are generally larger than the first sizes S1. Thus, in the case of the embodiments of FIG. **1**, the respective distribution gradients are characterized with an increased distribution of the Y_2O_3 particles of the first sizes S1 remote from the nose cone or ogive tip **140** in the aft portion **16** and an increased distribution of the MgO particles of the second sizes S2 proximate to the nose cone or ogive tip **140** in the forward portion **15**. In the case of the embodiments of FIG. **2**, the respective distribution gradients are characterized with an increased distribution of the Y_2O_3 particles of the first sizes S**1** remote from the nose cone or ogive tip **140** and along the inner portions **18** in the aft portion **16** and an increased distribution of the MgO particles of the second sizes S**2** proximate to the nose cone or ogive tip **140** and along the outer portions **17** in the forward portion **15**.

With reference to FIGS. **3** and **4** and in accordance with embodiments, the unitary radome layer **13** may have at least one of a rounded (e.g., spherical, hemi-spherical, etc.) shape **301** (see FIG. **3**) and a flattened shape **401** (see FIG. **4**). In either or other cases, the unitary radome layer **13** may include the first and second nano-composite formulations **11** and **12**, as noted above, with the respective distribution gradients. Thus, in exemplary cases, the unitary radome layer **13** with the rounded shape **301** of FIG. **3** may have an increased distribution of the first nano-composite formulation **11** toward the interior surface of the curvature and an increased distribution of the second nano-composite formulation **12** toward the exterior surface of the curvature. Similarly, the unitary radome layer **13** with the flattened shape **401** of FIG. **4** may have an increased distribution of the first nano-composite formulation **11** toward one side thereof and an increased distribution of the second nano-composite formulation **12** toward the other side thereof.

With reference to FIG. **5**, a unitary radome layer assembly method is provided. The method initially includes designing a unitary radome layer with first and second portions (such as the unitary radome layer **13** with the nose cone or ogive shape **14** and the first, front or forward portions **15** and the second, rear or aft portions **16** of FIGS. **1** and **2**, the unitary radome layer **13** with the rounded shape **301** of FIG. **3** or the unitary radome layer **13** with the flattened shape **401** of FIG. **4**) such that the first portions are more durable than the second portions and such that the second portions are more optically transparent than the first portions (block **501**). The method further includes providing first and second nano-composite formulations together in a unitary radome layer mold (such as a mold with a nose cone or ogive shape as in FIGS. **1** and **2**) where the second nanocomposite formulation has a hardener and a higher effective density than the first nanocomposite formulation (block **502**). The method then includes an operation of generating respective distribution gradients for the first and second nanocomposite formulations prior to curing (e.g., sintering) (block **503**).

In accordance with further embodiments and as shown in FIG. **5**, the method may also include controlling undesirable separation parameters of the first and second nanocomposite formulations (block **504**) and an addition of materials to at least one of the first and second nanocomposite formulations to adjust at least one of respective effective densities and respective sedimentation rates thereof (block **505**). The controlling of the undesirable separation parameters of block **504** may include, for example, an ultrasonic assist process executed with respect to the first and/or the second nano-composite formulations.

The first and second formulations may be suspended in fluid or provided as dry powders. In the latter case, it is to be understood that the dry powders may not be easily separated using centrifugal force. Here, an ultrasonic agitator can be attached to the centrifuge to ultrasonically assist separation and dispersion processes. The ultrasonic agitation disrupts attractive van der Walls forces between the particles of the first and second formulations to allow them to more easily migrate or glide through the volume. Also, since the hardener of the second nano-composite formulation can tend to lower the effective density of the second nano-composite formulation, a third phase or material that may be optically benign can be added to the second nano-composite formulation to increase the effective density of the second nano-composite formulation beyond that of the first nano-composite formulation.

In accordance with embodiments, the generating of the respective distribution gradients of block **503** may include defining the respective distribution gradients relative to a unitary radome layer axis, such as the lateral axis A**1** of FIGS. **1** and **2**, or to multiple unitary radome layer axes, such as the lateral axis A**1** and the central longitudinal axis A**2** of FIGS. **1** and **2** (block **5031**). In addition, the generating of the respective distribution gradients of block **503** may further include placing the unitary radome layer mold with the first and second nanocomposite formulations in a centrifuge (block **5032**) and activating the centrifuge to rotate the unitary radome layer mold with the first and second nanocomposite formulations about the unitary radome layer axis or about the multiple unitary radome layer axes (block **5033**).

With reference to FIG. **6**, the generating of the respective distribution gradients of block **503** is illustrated for the case of the unitary radome layer **13** having the nose cone or ogive shape **14** and the respective distribution gradients being defined relative to the lateral axis A**1**. In this case, the unitary radome layer **13** is coupled to a centrifuge **601** prior to curing of the curable material and the centrifuge **601** is activated to rotate the unitary radome layer **13** about the lateral axis A**1**. Such rotation produces centrifugal forces that are applied to the first and second nano-composite formulations **11** and **12** that result in the generation of an artificial gravitational field. Within this artificial gravitational field, the first and second nano-composite formulations **11** and **12** segregate from one another due to the second nano-composite formulation **12** having the higher effective density such that the second nano-composite formulation **12** pools at the forward portion **15** and the first nano-composite formulation **11** pools at the aft portion **16**.

With reference to FIG. **7**, in an event the centrifuge **601** of FIG. **6** were modified to rotate the unitary radome layer **13** about the central longitudinal axis A**2** or in an event the unitary radome layer **13** were placed into a new centrifuge, rotation of the unitary radome layer **13** about the central longitudinal axis A**2** prior to curing can lead to a further pooling of the second nano-composite formulation **12** along the outer portions **17** in the forward portion **15** and a further pooling of the first nano-composite formulation **11** along the inner portions **18** in the aft portion **16**.

It is to be understood that the invention described herein can be employed jointly with EMI protection as explained below with reference to FIGS. **8-15**.

As will be discussed below, a durable optical window is provided for use in LWIR applications for example. A standard optical window with a core layer formed of zinc sulfide (ZnS) is augmented with a nanocomposite optical ceramic (NCOC) cladding layer. Both the core and the cladding may be formed using NCOC powder-process sintering/HIPing processes. The cladding is generally only thick enough to meet strength/impact goals while the bulk of the window is formed of the highly transparent ZnS. In addition, an electromagnetic interference (EMI) treatment layer is interposed between the two core and cladding layers to provide EMI protection. The EMI treatment layer may be a deposited films or a microtextured (moth eye) grid on one or more surfaces. The durable optical window may also include anti-reflection and adhesive layers.

With reference to FIG. **8**, an optical window **10** is provided and includes multiple anti-reflection coatings between which additional layers are interleaved. In detail, the optical window **10** includes an outermost anti-reflection coating **11**, an outer-intermediate anti-reflection coating **12**, a cladding or outermost window layer (hereinafter referred to as an "outermost window layer") **13** that is interleaved between the outermost anti-reflection coating **11** and the outer-intermediate anti-reflection coating **12**, an innermost anti-reflection coating **14**, an inner-intermediate anti-reflection coating **15**, a core or innermost window layer (hereinafter referred to as an "innermost window layer") **16** that is interleaved between the innermost anti-reflection coating **14** and the inner-intermediate anti-reflection coating **15** and an EMI treatment layer **17**.

The EMI treatment layer **17** is located or interleaved between the outer-intermediate anti-reflection coating **12** and the inner-intermediate anti-reflection coating **15**. The EMI treatment layer **17** serves to provide for EMI protection for the optical window **10**. In its position interleaved between the innermost anti-reflection coating **14** and the inner-intermediate anti-reflection coating **15**, the EMI treatment layer **17** is protected from external and/or environmental conditions for which exterior EMI layers are not normally suitable.

The optical window **10** may further include an adhesive layer **18**. Such an adhesive layer **18** may be disposed adjacent to the EMI treatment layer **17** and may include at least one or more of polyethylene, polystyrene, polypropylene, low melting temperature glasses, a thiol and a urethane.

As shown in FIG. **8**, the optical window **10** and the various components and layers thereof may have a curved shape **101**. More particularly, the optical window **10** and the various components and layers thereof may have a nose-cone shape for provision at a forward end of an aircraft or a missile.

In accordance with embodiments, the outermost window layer **13** may include nanocomposite optical ceramic (NCOC) material and, in some cases, may include multiple NCOC materials and possibly hardening materials with one or more gradients defined therein. Meanwhile, the innermost window layer **16** may include a single phase material, such as quartz or zinc sulfide (ZnS). In any case, the outermost window layer **13** may be harder or substantially harder than the innermost window layer **16** (e.g., the outermost window layer **13** may be up to 5 or more times harder than the innermost window layer **16**). The innermost window layer **16** may be thicker or substantially thicker than the outermost window layer **13**.

With reference to FIG. **9**, which includes some but not all the features of FIG. **8** for purposes of clarity, a thickness of the optical window **20** may be variable at various locations where the optical window **10** and the various components and layers thereof have a curved or nose-cone shape. For example, in the case of the optical window **10** having the nose-cone shape, the optical window **10** may have a maximum thickness T**1** along a central longitudinal axis A thereof a lesser thickness T**2** at terminal side edges thereof and a decreasing thickness with increasing radial distance from the central longitudinal axis A. In addition, as shown in FIG. **9**, the innermost window layer **16** may be thicker than the outermost window layer **13** along the central longitudinal axis A and at the terminal side edges. Moreover, while the outermost window layer **13** and the innermost window layer **16** both may exhibit decreasing thicknesses with increasing radial distance from the central longitudinal axis, the degree of the decrease may be more pronounced in the innermost window layer **16**.

With continued reference to FIG. **8** and with additional reference to FIGS. **10** and **11**, certain features of the EMI treatment layer **17** will now be described. As shown in FIG. **8**, the EMI treatment layer **17** is interposed between the outermost surface **150** of the inner-intermediate anti-reflection coating **15** and either an innermost surface **120** of the outer-intermediate anti-reflection coating **12** or an innermost surface (not shown) of the adhesive layer **18**. The EMI treatment layer **17** may be substantially thinner than the outermost window layer **13** and, in some cases, the innermost window layer **16** as well. The EMI treatment layer **17** may exhibit greater losses as compared to either the outermost window layer **13** or the innermost window layer **16** but, since a thickness of the EMI treatment layer **17** is relatively small, such losses can be limited. In any case, the EMI treatment layer **17** may include or be formed as at least one of a conductive grid **170** (see FIG. **10**) and a conductive film **171** (see FIG. **11**).

In the case of the EMI treatment layer **17** being provided as a conductive grid **170** as in FIG. **10**, the outermost surface **150** of the inner-intermediate anti-reflection coating **15** may be micro-textured (e.g., as at least one of a deposited geometric optic coating pattern and a micro-textured physical optic coating pattern) to form grooves in which the material of the EMI treatment layer **17** can sit. For example, the conductive grid **170** can be formed with a moth-eye pattern **20** where the outermost surface **150** (see FIG. **8**) includes an array of raised hexagonal protrusions **201** that are separated from one another by inter-protrusion grooves **202**. During processing of the optical window **10**, materials of the EMI treatment layer **17** are disposed or deposited within these inter-protrusion grooves **202** and subsequently cured therein to form the EMI treatment layer **17**.

With reference to FIG. **12** and in accordance with further embodiments, an additional anti-reflective coating **501** may be interposed between the innermost anti-reflection coating **14** and the inner-intermediate anti-reflection coating **15**. This additional anti-reflection coating **501** may also be displaced from the inner-intermediate anti-reflection coating **15** to define a thermal management space **502** there between. In operational conditions, this thermal management space **502** may be supplied with coolant, such as air flow or fluid, or a heating element, such as an electrically resistive element, to maintain an appropriate operating temperature of the optical window **10**.

With reference to FIG. **13**, a method of assembling an optical window, such as the optical window **10** with the curved shape as described herein, is provided. As shown in FIG. **13**, the method includes pre-processing core layer material (block **601**), disposing electromagnetic interference (EMI) treatment layer material onto the core layer material (block **602**), providing cladding layer material to sandwich the EMI treatment layer material between the cladding layer material and the core layer material (block **603**) and post-processing at least the core layer material and the cladding layer material (block **604**). As noted above, the cladding layer material may include a nanocomposite optical ceramic (NCOC) and, in some cases, may include multiple NCOC materials and possibly hardening materials with one or more gradients defined therein, and the core layer material may include a single phase material such as zinc sulfide (ZnS).

In accordance with embodiments, the pre-processing of the core layer material and the cladding layer material of block **601** and **603** may include at least one or more of sintering and hot isostatic pressurizing (HIPing). Similarly, the post-processing of at least the core layer material and the cladding layer material of block **604** may include at least one or more of sintering and HIPing.

With reference to FIG. **14** and in accordance with embodiments, the providing of the cladding layer material of block **603** may include placing pre-processed core layer material and EMI treatment layer material in a fixture **701** that is formed to set a cladding layer thickness and subsequently depositing the cladding layer material into the space **702** in the fixture **701** between the pre-processed core layer material and the EMI treatment layer material.

With reference to FIG. **15** and in accordance with alternative embodiments, the providing of the cladding layer material of block **603** may include pre-processing both the core layer material and the cladding layer material, sandwiching the EMI treatment layer material between the core and cladding layer materials and at least one or more of sintering and HIPing the various layers together.

It is to be understood that the invention described herein can be employed jointly with a phase gradient nanocomposite layer.

While the preferred embodiments to the invention have been described, it will be understood that those skilled in the art, both now and in the future, may make various improvements and enhancements which fall within the scope of the claims which follow. These claims should be construed to maintain the proper protection for the invention first described.

What is claimed is:

1. A unitary radome layer assembly method, comprising:

designing a unitary radome layer with first and second portions, the first portions being more mechanically durable than and with increased hardener density relative to the second portions and the second portions being more optically transparent than the first portions;

providing first and second nanocomposite formulations together in a unitary radome layer mold, the second nanocomposite formulation having a hardener and a higher effective density than the first nanocomposite formulation; and

generating respective distribution gradients for the first and second nanocomposite formulations prior to curing.

2. The unitary radome layer assembly method according to claim **1**, wherein the generating of the respective distribution gradients comprises:

defining the respective distribution gradients relative to a unitary radome layer axis;

placing the unitary radome layer mold with the first and second nanocomposite formulations in a centrifuge; and

activating the centrifuge to rotate the unitary radome layer mold with the first and second nanocomposite formulations about the unitary radome layer axis.

3. The unitary radome layer assembly method according to claim **1**, wherein the generating of the respective distribution gradients comprises:

defining the respective distribution gradients relative to multiple unitary radome layer axes;

placing the unitary radome layer mold with the first and second nanocomposite formulations in a centrifuge; and

activating the centrifuge to rotate the unitary radome layer mold with the first and second nanocomposite formulations about the multiple unitary radome layer axes.

4. The unitary radome layer assembly method according to claim **1**, wherein the designing comprises designing the unitary radome layer to have at least one of an ogive shape, a rounded shape and a flattened shape.

5. The unitary radome layer assembly method according to claim **1**, further comprising controlling separation parameters of the first and second nanocomposite formulations.

6. The unitary radome layer assembly method according to claim **5**, wherein the controlling of the separation parameters comprises ultrasonic assist processes.

7. The unitary radome layer assembly method according to claim **1**, further comprising adding materials to at least one of the first and second nanocomposite formulations to adjust at least one of respective effective densities and respective sedimentation rates thereof.

8. A unitary radome layer assembly method, comprising:

designing an ogive shaped unitary radome layer comprising a tip and with first and second portions, the first portions being disposed proximate to the tip and being more mechanically durable than and with increased hardener density relative to the second portions and the second portions being disposed remotely from the tip and being more optically transparent than the first portions;

providing first and second nanocomposite formulations together in a unitary radome layer mold having an ogive shape, the second nanocomposite formulation having a hardener and a higher effective density than the first nanocomposite formulation; and

generating respective distribution gradients for the first and second nanocomposite formulations relative to an axis of the ogive shape prior to curing.

9. The unitary radome layer assembly method according to claim **8**, wherein the generating of the respective distribution gradients comprises:

defining the respective distribution gradients relative to a lateral axis of the unitary radome layer which is transversely oriented relative to a central longitudinal axis thereof;

placing the unitary radome layer mold with the first and second nanocomposite formulations in a centrifuge; and

activating the centrifuge to rotate the unitary radome layer mold with the first and second nanocomposite formulations about the lateral axis.

10. The unitary radome layer assembly method according to claim **9**, wherein the generating of the respective distribution gradients comprises:

defining the respective distribution gradients relative to the lateral axis and an additional axis; and

activating the centrifuge to rotate the unitary radome layer mold with the first and second nanocomposite formulations about the lateral axis and the additional axis.

11. The unitary radome layer assembly method according to claim **8**, further comprising controlling separation parameters of the first and second nanocomposite formulations.

12. The unitary radome layer assembly method according to claim **8**, further comprising adding materials to at least one of the first and second nanocomposite formulations to adjust at least one of respective effective densities and respective sedimentation rates thereof.

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